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TITLE: ACCELERATOR POWER CONCEPTS USING ISOLATED TRANSMISSION LINES

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ACCELERATOR POWER CONCEPTS USING ISOLATED TRANSMISSION LINES

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This paper outlines the rationale and the advantages of using multiple transmission-line sections isolated by transit time and inductance in accelerating high-current (≥10 kA), short-pulse (≤100 ns) particle beams to the multimegavolt level. The main advantages of this system include reducing the number of output switches required per output pulse by nearly an order of magnitude over conventional systems and increasing the system capability for repetition-rate operation. The isolated transmission-line concept is developed and possible modes of operation outlined. In addition, a point design of a 10-kA short-pulse accelerator is presented.

Introduction

The accelerator power schemes currently used in directed energy systems such as ETA/ATA[1] require many high-quality (high voltage, low inductance, low jitter, and high repetition rate) switches to accelerate single pulses in sequence. These switches are used in a primary role in the acceleration scheme and, therefore, must be high quality. The isolated transmission-line accelerator (ITLA) power scheme presented here uses high-power switches in a secondary role that requires lower quality units. In addition, ETA/ATA type acceleration power schemes use the switching action of one switch only one time. The ITLA scheme uses the effect of one switch many times through transit-time isolation. The ITLA power scheme can reduce the number of switches required by an ETA/ATA system by up to a factor of 10 or provide acceleration power for up to 10 simultaneous ETA/ATA type pulses with the same number of switches. Another advantage of the ITLA power scheme is that the system is not limited by ferrite size like the ETA/ATA system, but can use the higher saturation flux density and slower frequency response of tape-wound iron cores.

ITLA Power System

The ITLA power concept will be developed with a progression of circuits and applications. The operation of a Blumlein line can be characterized as voltage vector inversion. The sum of the voltage vectors from point A to point C in the generalized Blumlein line of Fig. 1 is zero before the switch is closed at time $t = 0$. If the Blumlein line is not loaded across points A and C, and the switch is closed at $t = 0$, a voltage shorting wave propagates down the transmission line to the open circuit at terminals AB and inverts the voltage vector in the bottom transmission line of Fig. 1. When the transient wave returns to the switch at $t = 2T_L$, the voltage vector in the bottom line is inverted everywhere as shown in Fig. 1b. At time $t = 2T_L$, the voltage potential available across points A and C for the entire line is $2V_o$. If an accelerator structure were connected to points A and C, the inversion switch opened, and a matched beam pulse injected ($I_p = V_o/4Z_L$, $T_p = .T_L$) at $t = 2T_L$, the pulse would be accelerated through a potential of V_o for a period of $2T_L$ until $t = 3T_L$. Note that the switch was opened in this example to make the accelerator operation compatible with transmission-line operation. This example is used only to illustrate the principle of voltage vector inversion and its use in an accelerator system.

If the transmission lines of Fig. 1 are chosen to be much longer than the pulse to be accelerated and, in

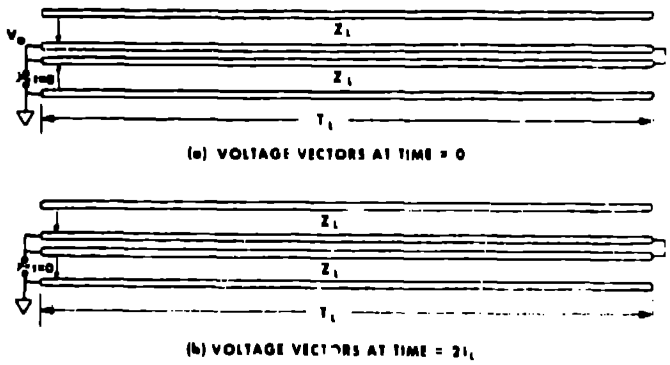

Fig. 1. Vector inversion of long transmission line.

particular, an integral number of pulse lengths, $T_L = mT_p$, then several pulses can be accelerated in parallel by the same set of transmission lines as shown in Fig. 2 where $m = 3$. Note that the arrangement shown in Fig. 2 consists of three dual Blumlein line accelerators connected in series, but with only one switch used for voltage inversion. The operation of the system shown in Fig. 2 can be made consistent with transmission-line operation (no switch opening required) in the following manner. The two transmission lines are initially charged to voltage, V_o. The switch is closed at $t = o$, and the voltage inversion takes place as noted for the system of Fig. 1. The accelerator structures of Fig. 2 must be designed so that they cause minimal discontinuities and, therefore, reflections of the inversion transients. Also, the accelerator structures are not loaded (no beam pulse present) during the inversion process. After the inversion wave has reached the open end and returned to point A in Fig. 2 ($t = 5.5\ T_p$), matched beam pulses ($I_p = V_o/4Z_L$, $T_p = T_L/3$) are simultaneously injected at points A, B, and C of Fig. 2. These pulses are all accelerated by a potential V_o for a period of $T_p = T_L/3$. The individual accelerator structures at points A, B, and C are isolated from each other by the transit time of the transmission line. This particular arrangement offers several obvious advantages. First, only one switch was used to accelerate three beam pulses. Second, the switch that was

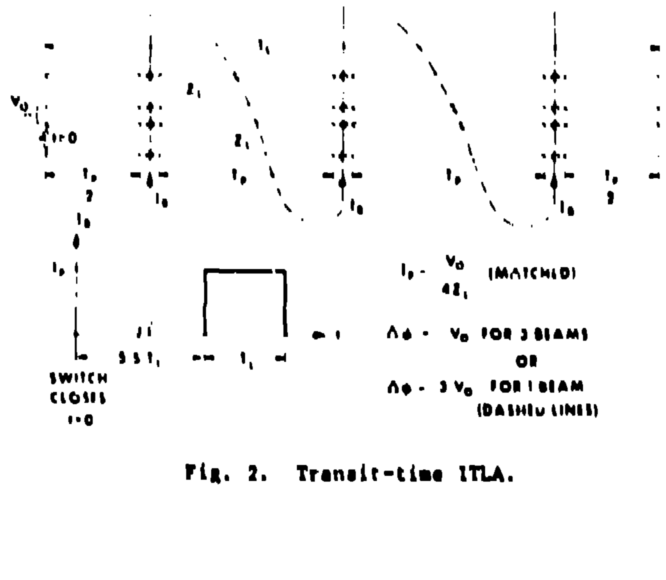

Fig. 2. Transit-time ITLA.

used only to invert the long transmission-line potential vectors does not have to be as high quality as a switch that is directly involved in coupling the accelerator to the beam. A third advantage, which is not immediately obvious, is the repetition-rate advantages of this pulse system. The bottom transmission-line section in Fig. 2 from input A to the switch can be lengthened and a transmission-line fan-out added to multiplex several switches, one in each leg of the fan-out. This arrangement permits higher rate operation through easy switch multiplexing. The short-duration transients caused by the impedance discontinuities of the transmission-line fan-out will not affect the accelerator structures and process because of the time delay between switch closure and acceleration.

Another mode of operation is indicated in Fig. 2 by the dashed lines. If the transit time, T_{AB}, of an accelerated particle from the output of accelerator section A to the input of section 3, could be made much less than the transmission-line transit time between structures of $T_{AB} \ll T_p$, then a single beam could, in principle, be accelerated m times (m = 3 for Fig. 2) by the same structure. In Fig. 2, the beam trajectory would be generally helical through the structure.

Because of the practical difficulties of providing the helical beam trajectory and the impossibility of reducing $T_{AB} \ll T_p$ for the system of Fig. 2, an obvious alternative is to deform the transmission lines into a helix and provide a straight beam trajectory. This method also makes the condition $T_{AB} \ll T_p$ feasible. This is the essence of the helical edge-wound strip-line accelerator (HEWSLA)[2] concept previously reported.

A major practical consideration that is desired in accelerator systems is one of enclosed potentials or grounded beam input and output ports. Another modification of the accelerator system of Fig. 2, shown in Fig. 3, is used to provide grounded beam input and output ports. Basically, inductive isolation is used to separate the bottom line from the top line and across which the opposite acceleration potential is applied. The beam trajectory passes through a closed metal cylinder or drift tube and does not experience the external decelerating field. The isolation inductance, L_I, of this path is made large so that the discharge time of the transmission-line capacitance, C_L, is long compared to the inversion time, T_i, or $\pi(L_I C_L)^{1/2} \gg T_i = mT_p$.

The inductance is made large by using tape-wound steel cores. In the electrical circuit of this scheme,

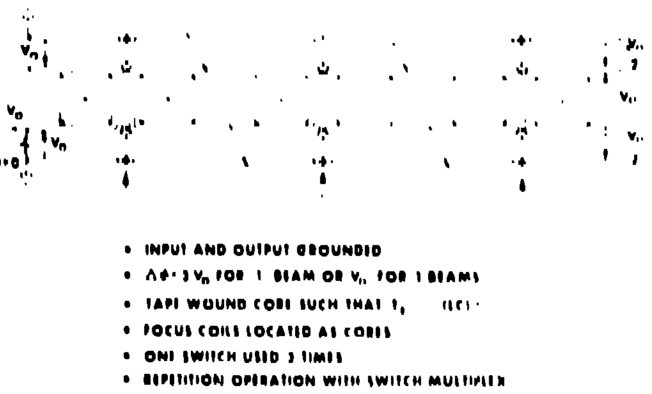

Fig. 3. Transit-time and inductance ITLA.

the isolating inductance appears in parallel with the beam pulse load during acceleration. Thus, this scheme can be labeled an induction accelerator. However, this concept can use lower frequency response and higher saturation flux materials (steel instead of ferrite) than the ETA/ATA type system.

The inductive isolation can be combined with transit time isolation to accelerate m pulses simultaneously (parallel) or 1 pulse m times (series). A conceptual design of a series ITLA module with m = 10 is shown in Fig. 4. A parallel ITLA is shown in Fig. 5 in which three pulses are accelerated simultaneously. The parallel module could be used in an accelerator system that would series the beam pulses after acceleration with beam handling techniques. In this context, the parallel ITLA can be considered as a beam chopper.

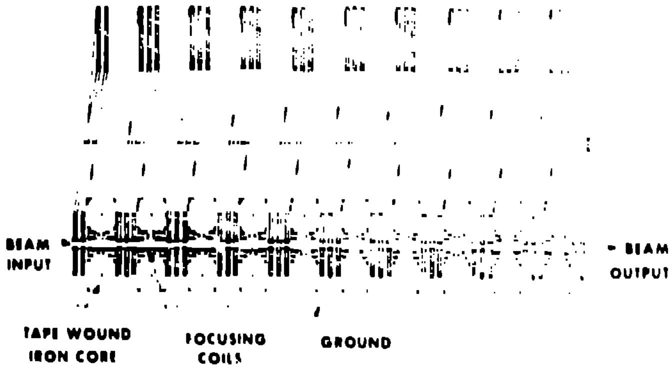

Fig. 4. Helical ITLA.

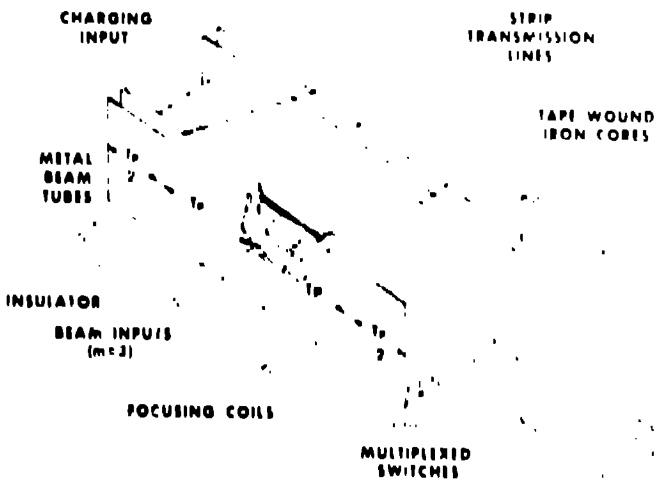

Fig. 5. Parallel ITLA.

Point Design

The parameters of a point design for an oil-insulated, series 10-kA accelerator are listed in Table I. The actual design procedure is described in a Los Alamos National Laboratory report to be published.[1]

Conclusions

Isolated transmission lines can be used in principle to reduce the number, quality, and requirements of high-power switches in pulsed accelerators. The parameters in Table I indicate that the number of switches in an ETA/ATA type system can be reduced by a factor of

10. Operation of the switches in a repetition mode is facilitated in the ITLA system because timing and switching requirements are reduced. Switch multiplexing is also facilitated by the use of switches in a secondary role rather than a primary role.

TABLE I

PARAMETERS FOR OIL-INSULATED SERIES ITLA MODULE

Line-charge voltage	(V)	= 2.5 E+05
Beam current	(A)	= 1.0 E+04
Beam pulse width	(s)	= 5.0 E-08
Line separation	(m)	= 3.1 E-02
Line width	(m)	= 3.1 E-01
Radius of helix	(m)	= 3.1 E+00
Line impedance	(Ω)	2.5 E-01
Dielectric strength	(V/m)	= 8.0 E+06
Relative dielectric constant		= 2.3 E+00
Number of parallel pulses		= 2
Multiple of minimum flux		= 1.2 E+00
Erection time	(s)	= 1.0 E-06
Resistive decay time	(s)	= 2.0 E-01
Area of core	(m^2)	= 3.0 E-01
Width of core along beam	(m)	= 2.9 E-01
RC limit of number of turns		= 1.0 E+05
LC limit of number of turns		= 5.0 E+00
Maximum number of turns		= 5.0 E+00
Acceleration per module	(V)	= 2.5 E+06

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2. W. C. Nunnally, "HEWSLA - Helical Edge-Wound Strip Line Accelerator," Los Alamos National Laboratory internal report (March 1979).

3. W. C. Nunnally, "Accelerator Power Concepts Using Isolated Transmission Lines," Los Alamos National Laboratory report LA-8750-MS (submitted for publication).